



Action TU1208 Civil Engineering Applications of Ground Penetrating Radar

Final Conference

Warsaw, Poland
25-27 September 2017

National Institute
of Telecommunications
of Poland

Final Report

Prof. Lara Pajewski

Sapienza University, Department of Information
Engineering, Electronics and Telecommunications,
Rome, IT (lara.pajewski@uniroma1.it)



COST is supported by the
EU Framework Programme Horizon2020

Talk Layout

- TU1208 basic information & main objective
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- Publication statistics & website
- Acknowledgements



TU1208 Basic Information & Main Objective



COST is supported by the
EU Framework Programme Horizon2020

TU1208 Basic Information

“Civil Engineering Applications of Ground Penetrating Radar”

- **Chair of the Action & GH**

Dr Lara Pajewski

“Sapienza” University (IT)

lara.pajewski@uniroma1.it

- **Science & Administrative Officers**

Dr Mickael Pero & Ms Carmencita Malimban

COST Association (BE)

- **Start date – End date**

4th April 2013 – 3rd October 2017

- **Website & social media**

www.GPRadar.eu

www.cost.eu/COST_Actions/tud/TU1208

www.facebook.com/COSTActionTu1208/

www.linkedin.com/company/9425227/

www.instagram.com/costactiontu1208/

www.twitter.com/TU1208GPR



TU1208 Main Objective

- Exchange and increase scientific-technical knowledge and experience of GPR techniques in civil engineering, while promoting throughout Europe the effective use of this safe and non-destructive technique.

By exploiting all COST networking tools and faithfully following COST's inclusiveness policy and key principles, the primary objective of the Action has been fully achieved. The Action has created a wide, pan-European, trans- and multidisciplinary network, which has generated and shared useful knowledge while building a critical mass of people with experience and competences in the GPR field.

The Action has established and strengthened active links between universities, research institutes, and companies working in this field, fostering and accelerating its long-term development in Europe.





COST Success Story



COST is supported by the
EU Framework Programme Horizon2020



“The Cities of Tomorrow: the Challenges of Horizon 2020”

Torino, Italy, 17-19 September 2014

TU1208 praised among running Actions as COST Success Story

TU1208 "Civil engineering applications of Ground Penetrating Radar" (Chair: Lara Pajewski, Roma Tre University) is an interdisciplinary Action and represents a milestone in GPR research, being the first European network ever existed in this field, in line with the spirit and goals of the ERA. In June 2014, it co-organised the 15th International Conference on Ground Penetrating Radar, the premier forum on GPR.



TU1208 Structure & Participants



COST is supported by the
EU Framework Programme Horizon2020

TU1208 Structure

GRANT HOLDER
Sapienza Innovazione*

**MANAGEMENT
COMMITTEE (MC):**
77 MC M & Subs + 24 MC Obs

MC CHAIR:
Dr Lara Pajewski

COST ASSOCIATION

SCIENCE OFFICER:
Dr Mickael Pero

ADMINISTRATIVE OFFICER:
Ms Carmencita Malimban

308 WG Members from 150 institutes

WG 1

**Novel GPR
Instrumentation**

WG 2

**GPR surveying of
transport
infrastructure,
utilities and voids**

WG 3

**EM modelling,
inversion, imaging,
data processing
techniques**

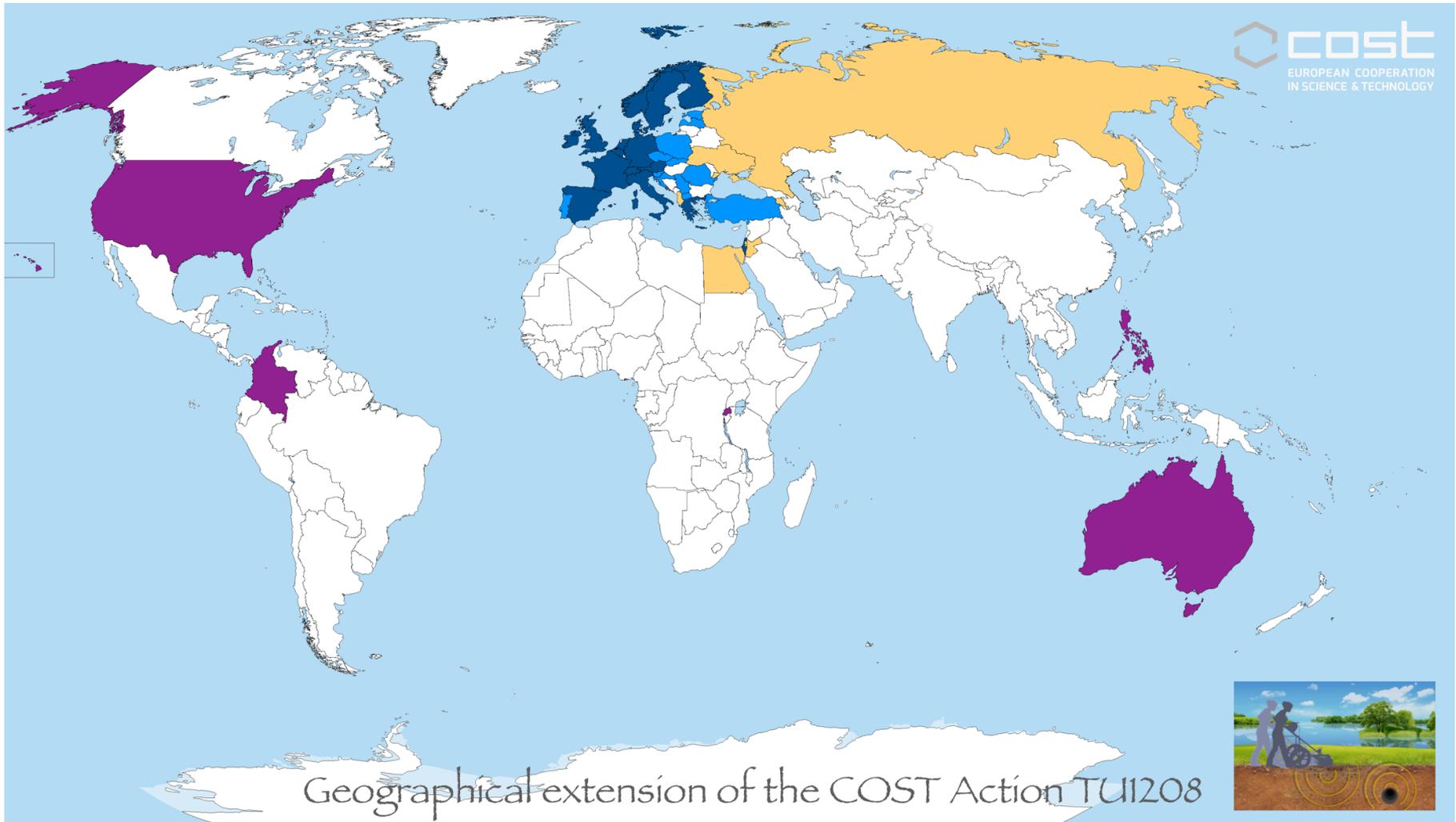
WG 4

**GPR applications
outside from CE &
GPR integration
with other NDT**

***GH Scientific Representative & Grant Manager: Prof Lara Pajewski**
GH Legal and Financial Representative: Prof Antonio Carcaterra

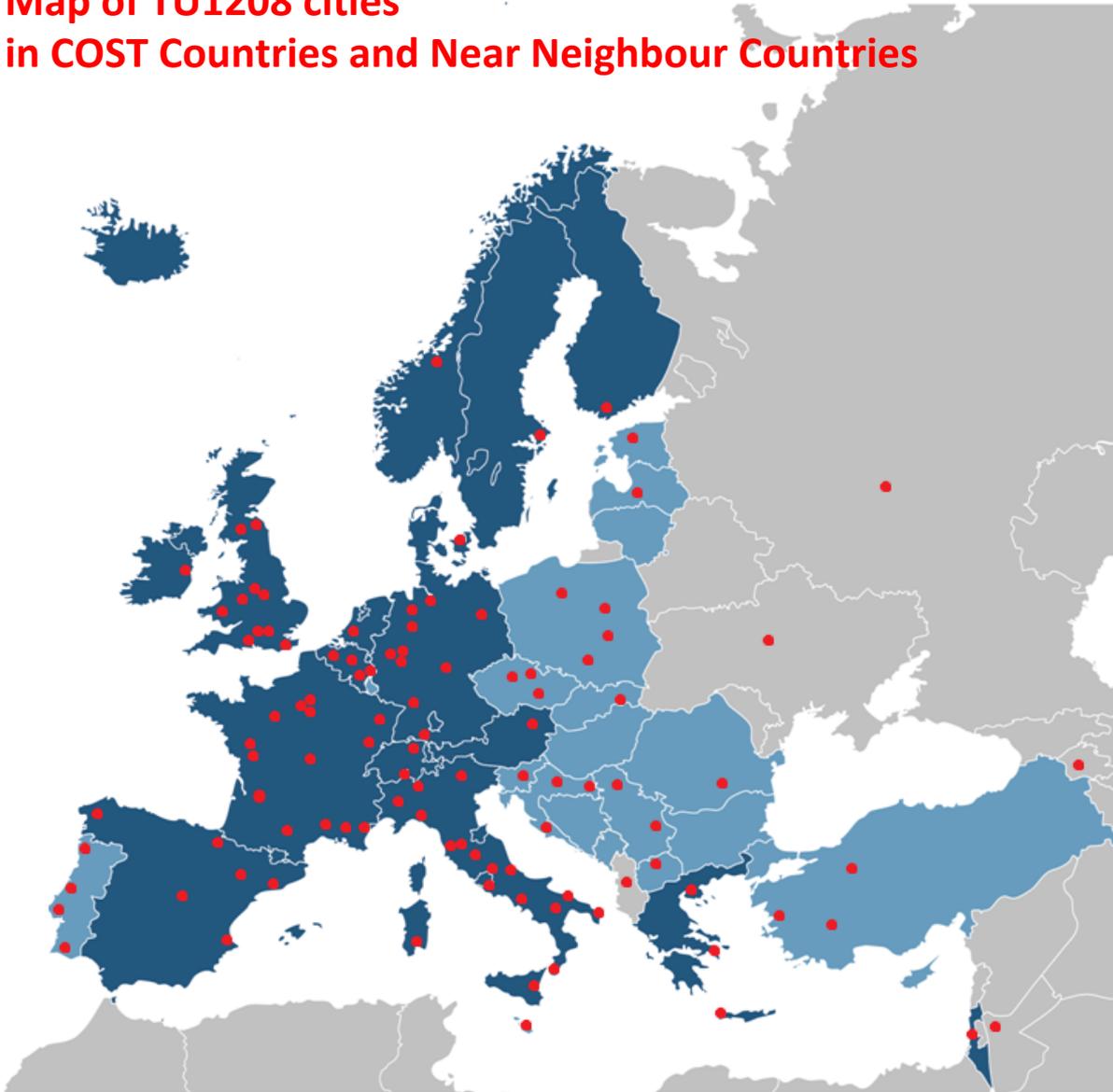
TU1208 Participants: 41 Countries

Austria, Belgium, Croatia, Czech Rep., Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Macedonia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom. Israel. **Albania, Armenia, Egypt, Jordan, Russia, Ukraine.** **Australia, Colombia, Hong Kong, Philippines, Rwanda, USA.**



TU1208 Participants: COST & NNC cities

Map of TU1208 cities in COST Countries and Near Neighbour Countries



Austria,
Belgium,
Croatia,
Czech Rep.,
Denmark,
Estonia,
Finland,
France,
fYR Macedonia,
Germany,
Greece,
Ireland,
Italy,
Latvia,
Malta,
Netherlands,
Norway,
Poland,
Portugal,

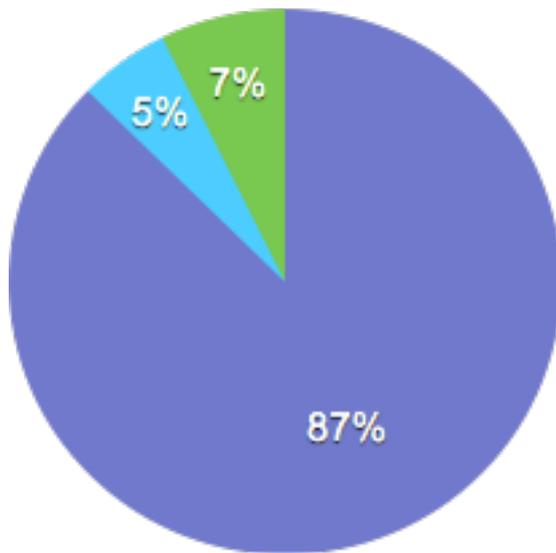
Romania,
Serbia,
Slovakia,
Slovenia,
Spain,
Sweden,
Switzerland,
Turkey,
UK.

Israel

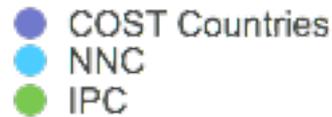
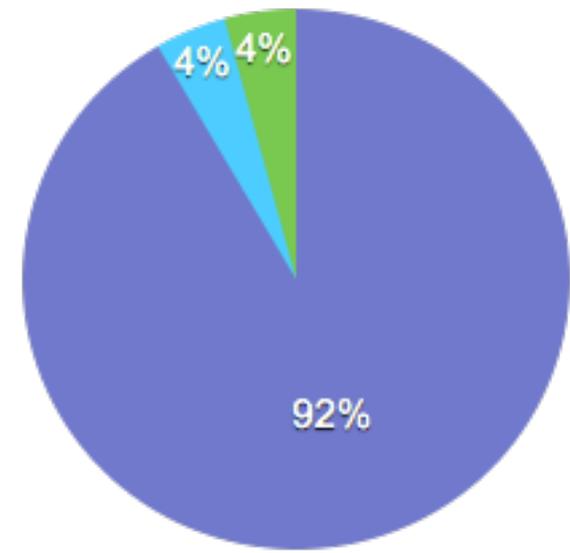
Albania,
Armenia,
Egypt,
Jordan,
Russia,
Ukraine.

TU1208 Participants: Statistics

TU1208 Institutes: 150

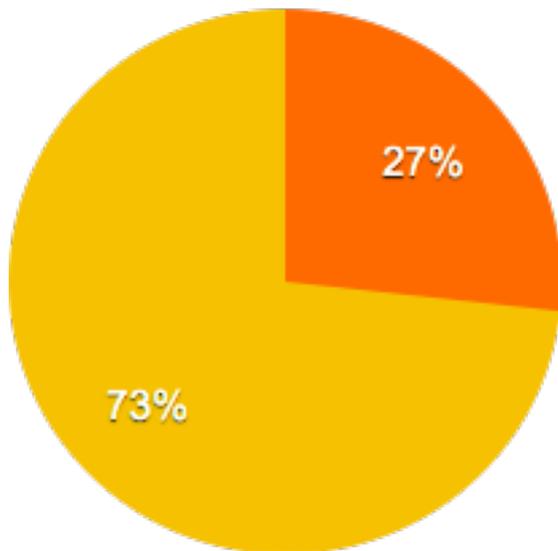


TU1208 Members: 308

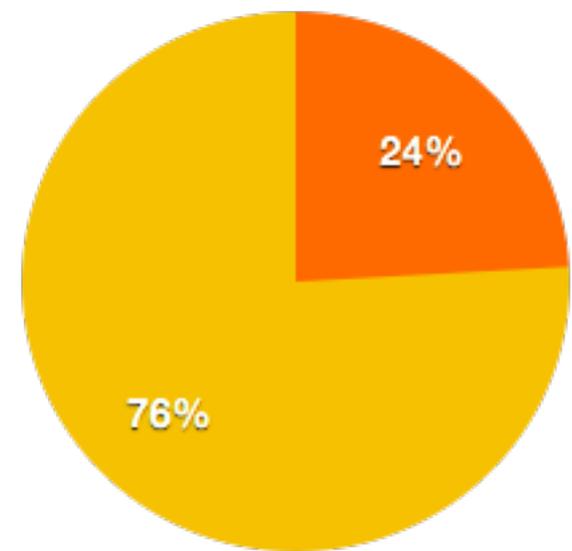


COST TU1208 Participants: Statistics

COST TU1208 Institutes



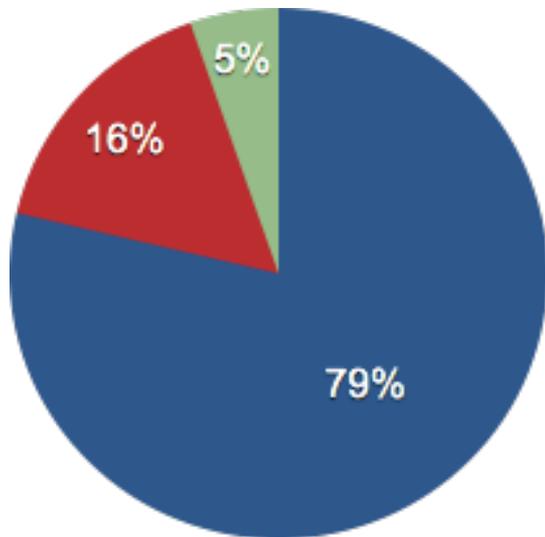
COST TU1208 Members



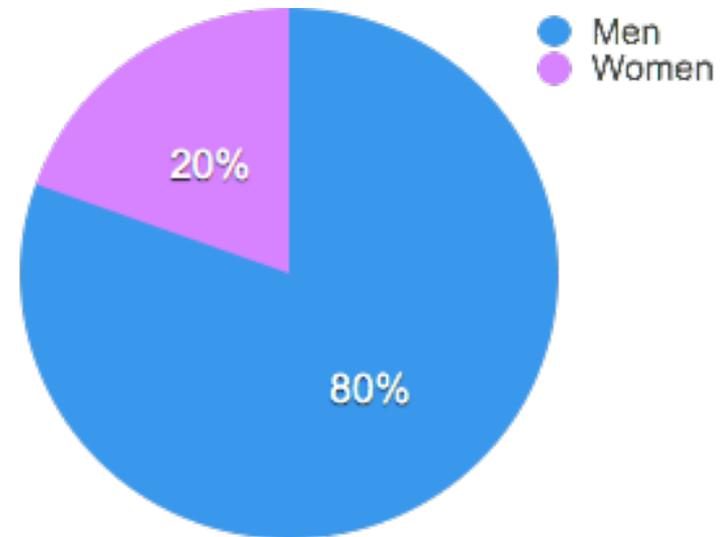
- Inclusiveness
- Research-intensive

TU1208 Participants:

Involvement of industry & public agencies – Gender balance



● Academia & Research
● Industry
● Public Agencies



● Men
● Women



Working Group 1



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WG1 of the COST Action TU1208

GRANT HOLDER
Sapienza Innovazione

**MANAGEMENT
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308 Members from 150 institutes

WG 1

**Novel GPR
Instrumentation**

WG 2

**GPR surveying of
transport
infrastructure,
utilities and voids**

WG 3

**EM modelling,
inversion, imaging,
data processing
techniques**

WG 4

**GPR applications
outside from CE &
GPR integration
with other NDT**

TU1208 WG1: Structure

WG1

Novel GPR Instrumentation



Project 1.1 Design, realization and optimization of GPR equipment for the monitoring of critical transport infrastructures (pavements, bridges and tunnels)

Project 1.2 Design, modelling and optimisation of GPR antennas

TU1208 WG1: State of the art

Civil engineering applications of Ground Penetrating Radar.

Eds: A. Benedetto & L. Pajewski. Publishing House: Springer. April 2015.
Book Series: "Springer Transactions in Civil and Environmental Engineering" DOI:10.1007/978-3-319-04813-0.

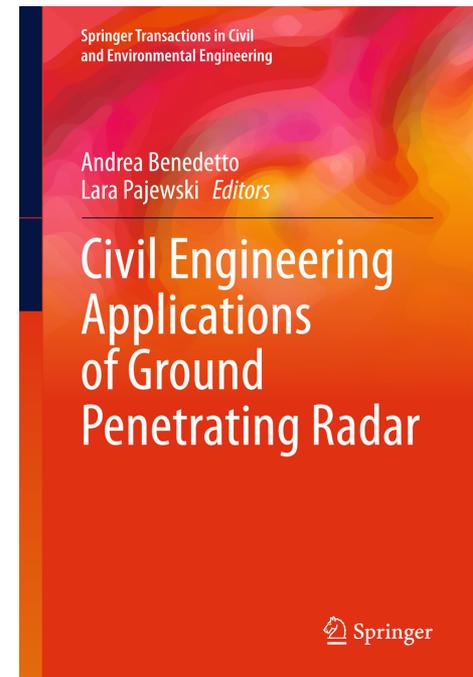
Part I – GPR Instrumentation

Advanced GPR equipment for civil engineering applications,

by Guido Manacorda, Raffaele Persico and
Howard F. Scott

Antennas for GPR Systems,

by Lara Pajewski, Fabio Tosti and Wolfgang
Kusayanagi



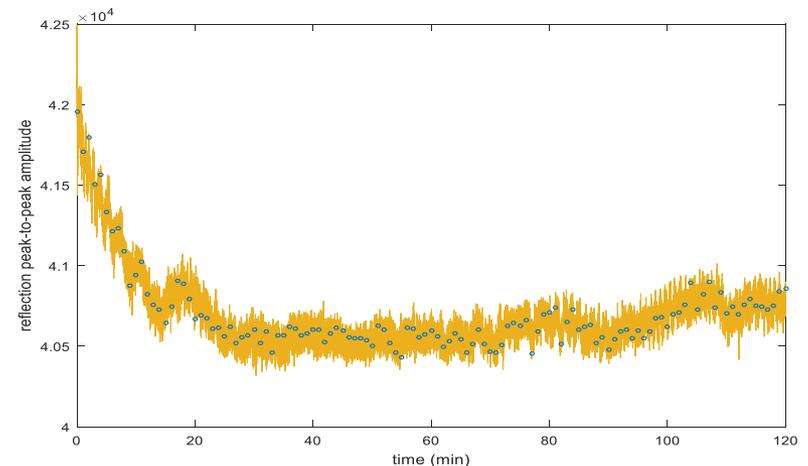
TU1208 WG1: New GPR systems

- Reconfigurable stepped-frequency GPR (Italy, Malta, Norway)
- Stepped-frequency ground-coupled GPR for roads & bridges (Norway)
- Cheap Frequency-Modulated Continuous-Wave GPR, for training purposes (Italy, Russia)
- Microwave GPR systems for road inspection (Finland)
- Lightweight radar system for tomographical reconstruction of circular structures (Belgium, Italy)
- Empirical method for the estimation of mechanical properties of roads from GPR data (Italy, Spain, United Kingdom)

TU1208 WG1: GPR system performance compliance

GPR systems shall be periodically calibrated and their performance verified, in accordance with the manufacturer's recommendations and specifications. We have proposed four tests, which can be periodically carried out to check the performance of GPR systems (Belgium, Czech Republic, France, Italy, Portugal, Serbia, Turkey).

1. **Signal-to-Noise ratio test**
2. **Signal stability test**
3. **Linearity in the time axis test**
4. **Long-term stability test**



TU1208 WG1: Safety issues in GPR prospecting

Recommendations for the Safety of People and Instruments in Ground-Penetrating Radar and Near-Surface Geophysical Prospecting



cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY
Action TU1208

EAGE
EUROPEAN
ASSOCIATION OF
GEOSCIENTISTS &
ENGINEERS

1. General recommendations
2. Challenging environmental situations
3. Risks associated to specific applications
4. First medical aid
5. GPR electromagnetic emissions
6. Safety of equipment and environment

Raffaele Persico	Institute for Archaeological and Monumental Heritage IBAM-CNR, Lecce, Italy
Antonio Provenzano	Città di Lecce Hospital, Lecce, Italy
Christiane Trela	Federal Institute for Materials Research and Testing, Berlin, Germany
Motoyuki Sato and Kazunori Takahashi	Tohoku University, Sendai, Japan
Steven Arcone	U.S. Army ERDC-Cold Regions Research and Engineering Laboratory, Hanover, USA
Steven Koppenjan ¹ and Larry G. Stolarczyk ²	¹ Special Technologies Laboratory, Santa Barbara, USA ² Stolar Institute of Applied Radio Geophysics, Raton, USA
Erica Carrick Utsi	EMC Radar Consulting, Ely, UK
Satoshi Ebihara ¹ and Kazushige Wada ²	¹ Osaka Electro-Communication University, Osaka, Japan ² Matsunaga Geo-survey Co. Ltd., Tokyo, Japan
Elena Pettinelli	“Roma Tre” University, Rome, Italy
Lara Pajewski	“Roma Tre” University, Rome, Italy

TU1208 WG1: Training schools

COST-ESoA-EuMA Training School on Future Radar Systems: Radar2020

I edition: Karlsruhe, Germany, May 5-9, 2014 - 6 Trainers and 16 Trainees

II edition: Karlsruhe, Germany, May 2-6, 2016 - 5 Trainers and 14 Trainees

Industry involvement: Daimler AG (German manufacturer of automobiles, motor vehicles and engines) delivered practical sessions on radar technologies for autonomous driving.



TU1208 WG1: Training schools

COST-ESoA-EurAAP Training School on Ultra Wide-Band Antennas, Technologies and Applications

Karlsruhe, Germany, April 20-24, 2015 - 4 Trainers and 18 Trainees

A series of UWB radar prototypes realised by the Technical University of Ilmenau were used for practical sessions on GPR, Through-the-Wall radar, detection of breathing and heart beating.



TU1208 WG1: Education Pack

Development of an open-access GPR Educational Package

The TU1208 Education Pack is intended for teaching GPR in the University. It will be available on the website of the Action by 3 November 2017.

The level of knowledge and experience on GPR is not the same in all Countries: This initiative will help professors and researchers in less research-intensive Countries to initiate new courses on GPR in their universities.

Module 1: GPR basic principles

Introduction to GPR

Overview on GPR applications

Electromagnetic properties of media

Module 2: GPR systems and antennas

Radar systems

GPR systems and antennas

Module 3: Civil-engineering applications of GPR

[...]



1. Iraklis Giannakis, UK

STSM Title: Numerical modelling of Ground-Penetrating Radar antennas

Dates: from 15-1-2014 to 21-3-2014

Location: Roma Tre University, Rome, Italy

Host: Lara Pajewski

2. Loredana Matera, IT

STSM Title: Tests, comparison and improvement plans for an innovative reconfigurable stepped-frequency GPR

Dates: from 1-6-2014 to 30-6-2014

Location: 3d radar, Trondheim, Norway

Host: Jacopo Sala

3. Raffaele Persico, IT

STSM Title: Use of GPR and standard geophysical methods to explore the subsurface

Dates: from 14-7-2015 to 24-7-2015

Location: University of Malta, Msida, MT

Host: Sebastiano D'Amico

4. Alessio Ventura, IT

STSM Title: Comparison of finite-difference and finite-integration methods in the time-domain for the simulation of GPR antennas and other electromagnetic applications

Dates: from 18-04-2016 to 22-04-2016

Location: The University of Edinburgh, Edinburgh, UK

Host: Antonis Giannopoulos

5. Alessandro Fedeli, IT (ECI)

STSM Title: Testing of a new lightweight radar system for tomographical reconstruction of circular structures

Dates: from 12-09-2016 to 23-09-2016

Location: Université catholique de Louvain, Louvain-La-Neuve, BE

Host: Sébastien Lambot

6. Margarita Chizh (RUS)

STSM Title: Design and realization of a Frequency-Modulated Continuous Wave (FMCW) GPR dedicated to educational purposes. Extension of interactive setup functionalities.

Dates: from 06-02-2017 to 02-04-2017

Location: Sapienza University of Rome, Rome, IT

Host: Vincenzo Ferrara



Working Group 2



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WG2 of COST Action TU1208

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Sapienza Innovazione

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COMMITTEE (MC):**
77 MC M & Subs + 24 MC Obs

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WG 1

Novel GPR
Instrumentation

WG 2

GPR surveying of
transport
infrastructure,
utilities and voids

WG 3

EM modelling,
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data processing
techniques

WG 4

GPR applications
outside from CE &
GPR integration
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TU1208 WG2: Structure



WG2 GPR Surveying of Pavements, Bridges, Tunnels, Buildings – Utility and Void Sensing

Project 2.1 ...critical transport infrastructures (pavements, bridges, tunnels)

Project 2.2 ...buildings

Project 2.3 ...underground utilities and voids, with a focus to urban areas

Project 2.4 ...construction materials

Project 2.5 Determination, by using GPR, of the volumetric water content in structures, sub-structures, foundations and soil

TU1208 WG2: Main achievements

1. The state of the art on the use of GPR in civil engineering was composed and open issues were identified. The few existing international/national guidelines/protocols for GPR inspection in civil engineering were reviewed and discussed.
2. Guidelines for investigating flexible pavement by using GPR have been prepared, with particular regard to layer-thickness assessment, moisture-content sensing, pavement-damage detection and classification, and other main GPR-based investigations in pavement engineering.
3. Guidelines for GPR sensing and mapping of underground utilities and voids, with a main focus on urban areas, have been prepared.
4. Guidelines for GPR assessment of concrete structures, with particular regard to inspections in bridges and tunnels, have been prepared.



TU1208 WG2: Main achievements

5. WG2 Members carried out a plethora of case studies where GPR was used to survey roads, highways, airport runways, car parkings, road tunnels, underground concrete tunnels, bridges, railways, buildings.

GPR was also employed to detect cables and pipes, as well as to inspect road construction materials, joints, concrete and wood.
6. WG2 contributed to the TU1208 Education Pack, an open-access educational package conceived to teach GPR in University courses.
7. In cooperation with the other Working Groups, WG2 organized a series of national events devoted to fostering the interaction with stakeholders, new potential GPR end-users, and interested citizens. During such events, participants could discover what is GPR and how this technique can be effectively used in civil engineering works as well as in different fields ("TU1208 GPR Road Show").



TU1208 WG2: Main achievements

8. In cooperation with other Working Groups, WG2 organized:

- Two half-day tutorials on Ground Penetrating Radar
- 7 Training Schools on Ground Penetrating Radar applications.



9. 9 STSMs funded and successfully carried out.

10. Catalogue of European Test Sites



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EU Framework Programme Horizon2020



Working Group 3



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WG3 of COST Action TU1208

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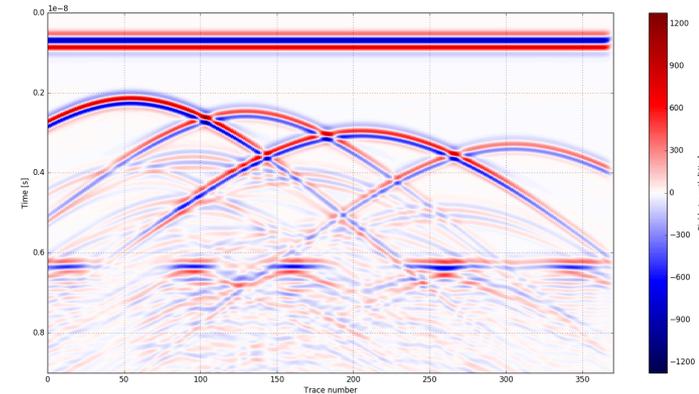
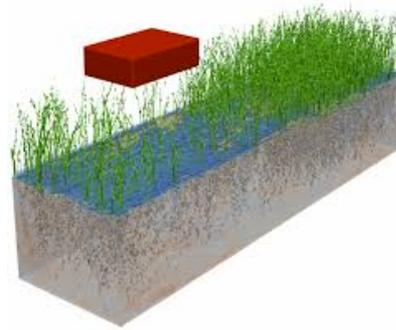
WG 4

GPR applications
outside from CE &
GPR integration
with other NDT

TU1208 WG3: Structure

WG3

EM Methods for Near
Field Scattering Problems
– Data Processing



Project 3.1 Electromagnetic modelling for GPR

Project 3.2 Imaging and inversion techniques for GPR

Project 3.3 Development of intrinsic models for describing near-field antenna effects, including antenna-medium coupling, for improved radar data processing using full-wave inversion

Project 3.4 Development of advanced data processing techniques for GPR

TU1208 WG3: Main achievements

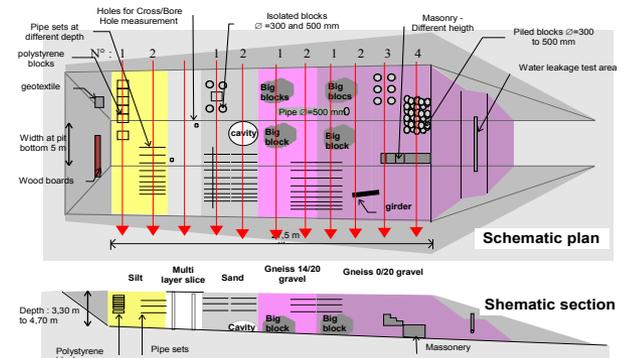


Development of freeware tools in TU1208

- The open source simulator gprMax
- E²GPR
- TWiNS-II
- SPOT-GPR 1.0
- PROEX GPR CONTROL

The TU1208 database of GPR data

A database of numerical and experimental GPR responses from natural and manmade structures that is at the disposal of the scientific community including geometrical and physical descriptions of the scenarios. Researchers working on electromagnetic modelling, inversion, imaging and data-processing techniques can use these radargrams as reference datasets to test and compare their approaches and algorithms.



TU1208 WG3: Main achievements

WG3 organized 4 Training Schools (and cooperated in further TSs):

COST-ESoA Training School on Microwave Imaging and Diagnostics

I ed.: Madonna di Campiglio, Italy, March 24-28, 2014. Co-organised TD1301.

II ed.: Taormina, Italy, October 14-18 2016. Co-organised with COST Action TD1301.

COST-Aristotle University of Thessaloniki Training School on Numerical modelling of Ground Penetrating Radar using gprMax

Thessaloniki, Greece, November 9-11, 2015

COST Training School on Electromagnetic modelling techniques for Ground Penetrating Radar

Split, Croatia, November 9-12, 2016

15 STSMs were funded and successfully carried out.



COST is supported by the
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Working Group 4



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WG4 of COST Action TU1208

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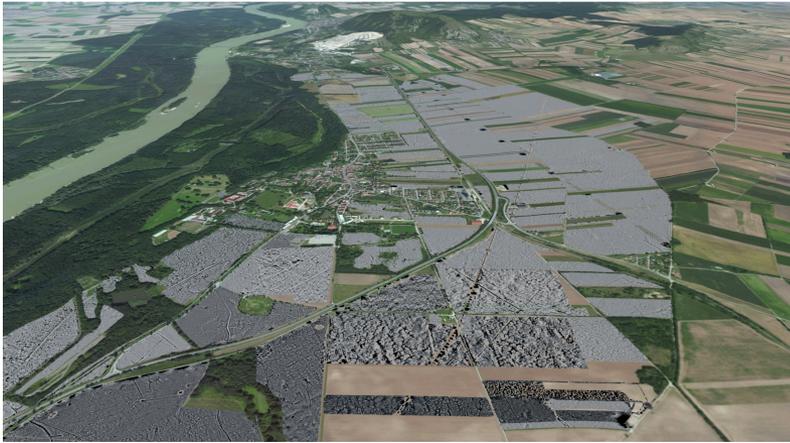
WG 3

EM modelling,
inversion, imaging,
data processing
techniques

WG 4

GPR applications
outside from CE &
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TU1208 WG4: Structure



WG4

Different applications of GPR and other NDT technologies in Civil Engineering

- Project 4.1** Advanced use of GPR for archaeological prospecting and cultural heritage diagnostics
- Project 4.2** Advanced use of GPR for the localisation and vital signs detection of buried and trapped people
- Project 4.3** Advanced use of GPR for the management and protection of water resources
- Project 4.4** Advanced use of GPR in association with other NDT methods

TU1208 WG4: Two main topics

1. Use of GPR outside from the civil engineering area

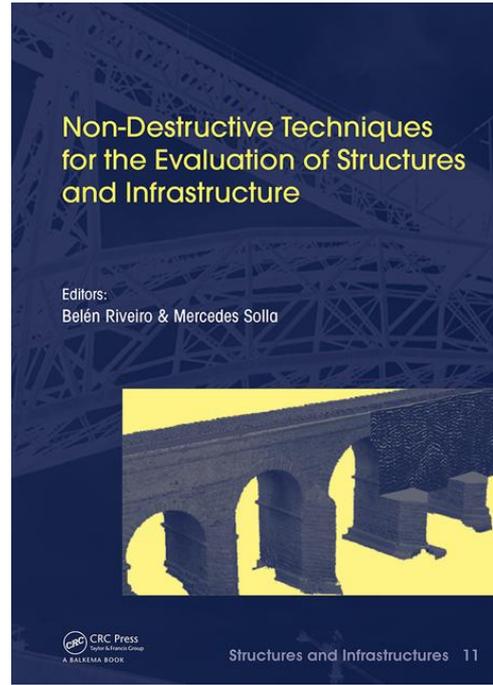
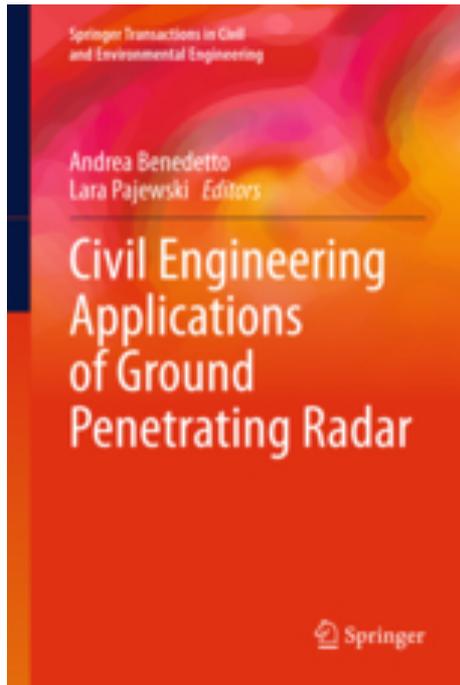
- ✓ archaeological prospecting
- ✓ cultural heritage diagnostics
- ✓ agriculture and management of water resources
- ✓ investigation of polluted industrial sites
- ✓ non-destructive testing of living tree trunks
- ✓ planetary exploration
- ✓ demining
- ✓ localization of people buried under avalanches and debris
- ✓ and more...

2. Integration of GPR with complementary non-destructive testing methods



TU1208 WG4: Main achievements

- The state of the art on WG4 topics was composed and open issues were identified.



Non-Destructive Techniques for the Evaluation of Structures and Infrastructure

Editors: Belén Riveiro and Mercedes Solla

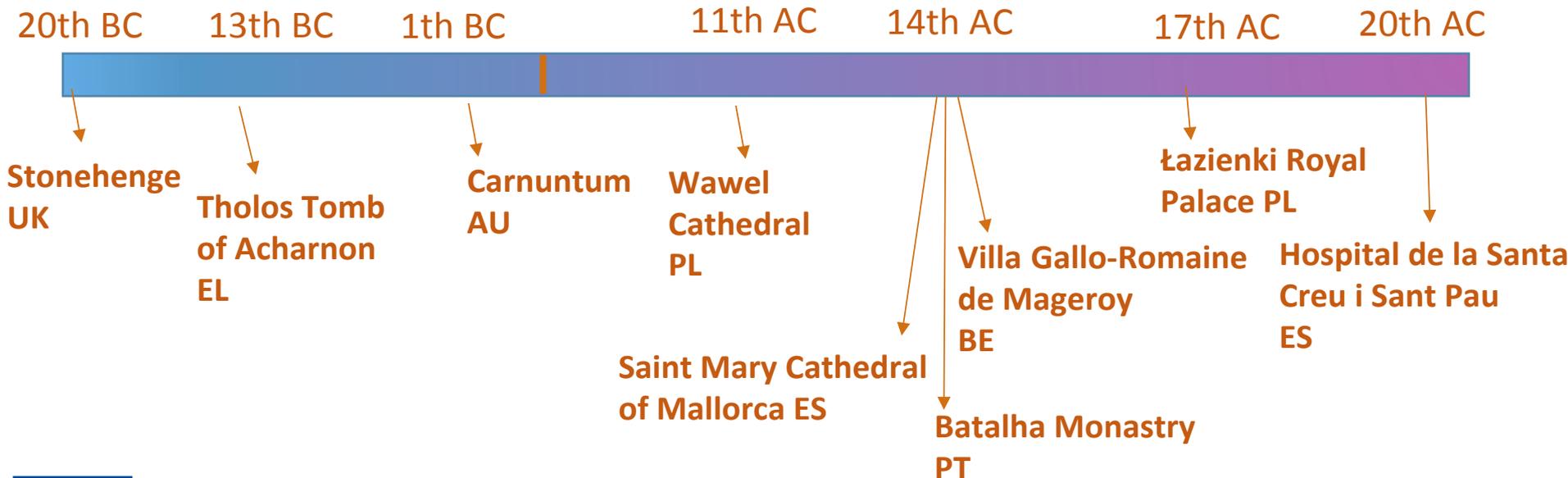
April 4, 2016 by CRC Press
Reference - 398 Pages
ISBN 9781138028104 - CAT# K26366



COST is supported by the
EU Framework Programme Horizon2020

TU1208 WG4: Main achievements

- Members of the COST Action TU1208 performed a number of cutting-edge GPR investigations in a plethora of different sites all over Europe, including well-known historical places such as Stonehenge (United Kingdom), Carnuntum (Austria), the Wawel Cathedral (Cracow, Poland), the Tholos Tomb of Acharnon (Athens, Greece), the Łazienki Royal Palace (Warsaw, Poland), and more.



TU1208 WG4: Main achievements

- Contribution to the Education Pack.
- Organization of 3 Training Schools (+ contribution to further TSs):

COST Training School on Applications of Ground Penetrating Radar in Urban Areas:
the Sensitive Case of Historical Cities

Cracow, Poland, May 5-7, 2015

COST Training School on Applications of GPR to civil engineering & archaeology

Msida, Malta, January 25-29, 2016

COST Training School on
Non-destructive testing techniques for
civil engineering

Barcelona, Spain, March 14-18, 2016

- 8 STSMs

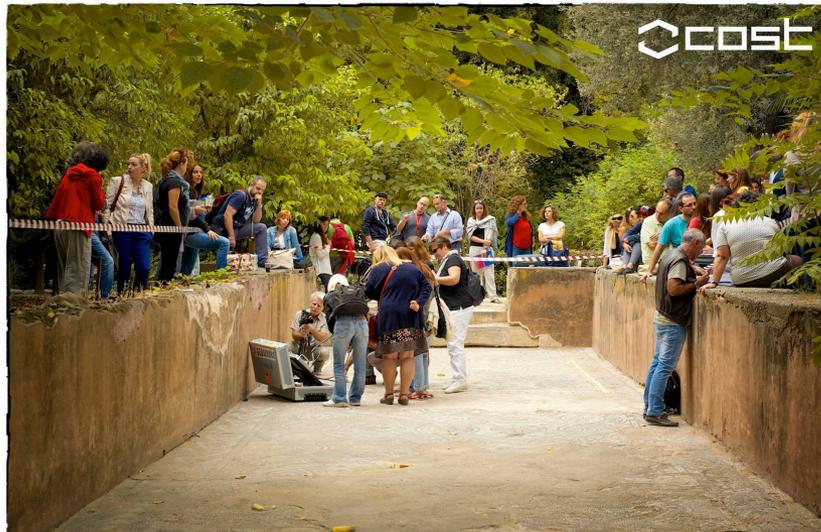


TU1208 WG4: Main achievements

■ Organization of Road Shows

*Use GPR in archaeology and cultural-heritage management.
Athens, September 27th-28th, 2016*

GPR technique explained to citizens while performing practical demonstrations in the National Gardens of Athens



COST is supported by the
EU Framework Programme Horizon2020

TU1208 WG4: Activities with children in Estonia

Using GPR to search for the treasure ...



Photos by Hannes Tonisson



COST is supported by the
EU Framework Programme Horizon2020

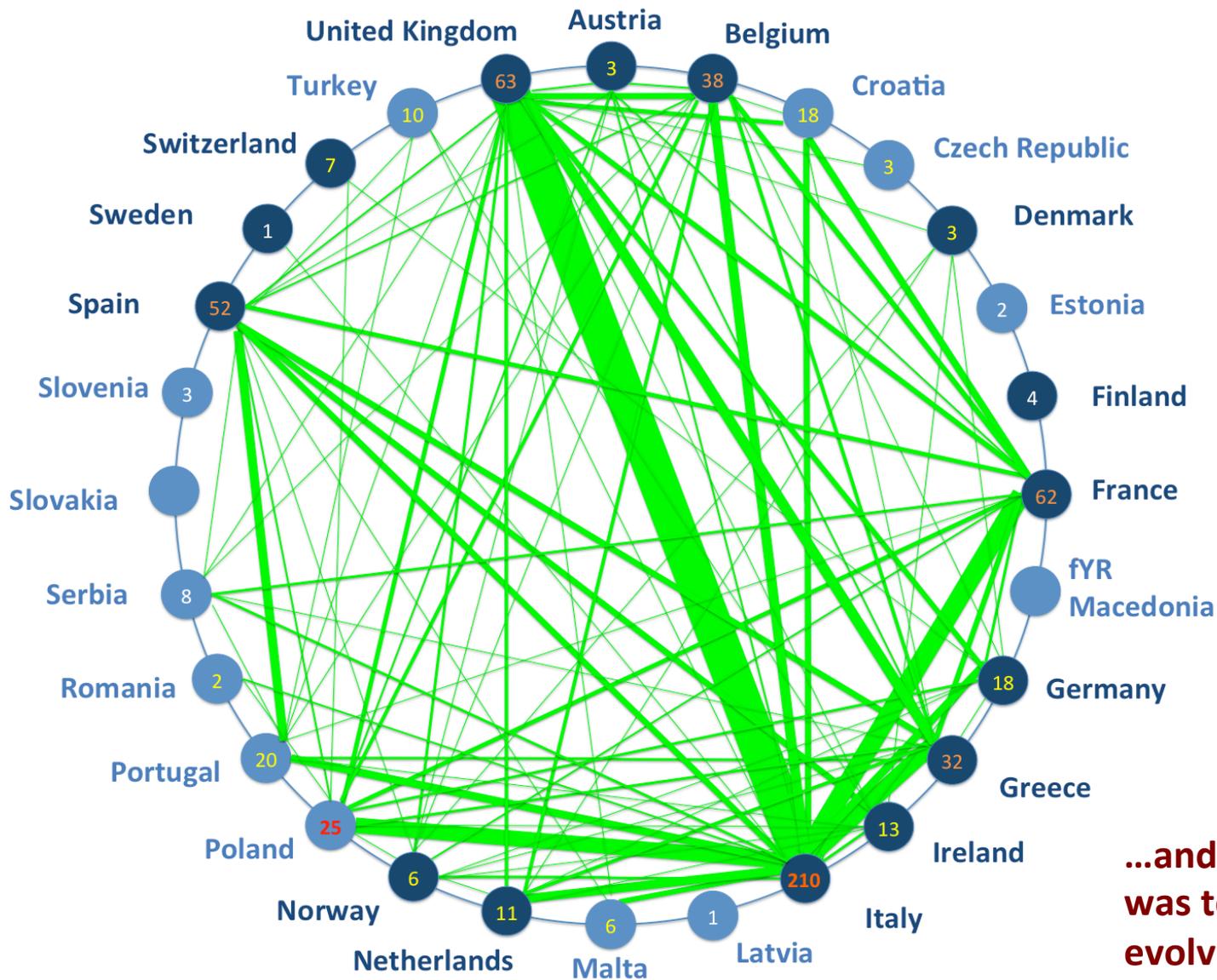


Publication statistics & website



COST is supported by the
EU Framework Programme Horizon2020

Publications on international peer-reviewed journals, books & conference proceedings with acknowledgement to TU1208: *Network of collaborations (COST Countries only)*



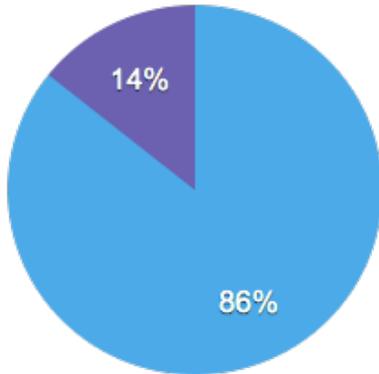
...and how touching it was to witness this map evolving with time



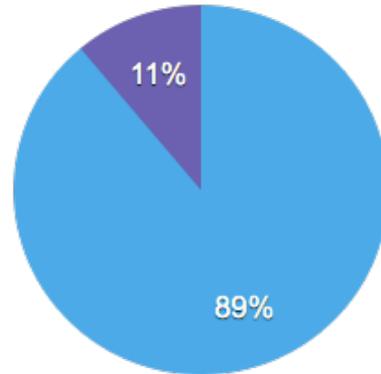
TU1208 Journal papers

- Research-intensive Countries only
- Inclusiveness Countries involved

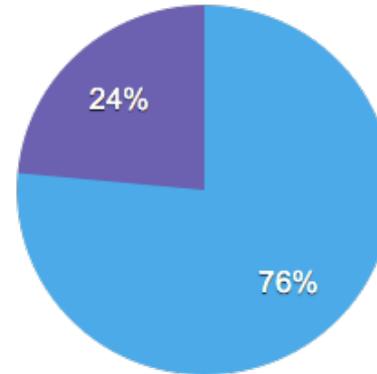
Year 1 (statistically non-significant)



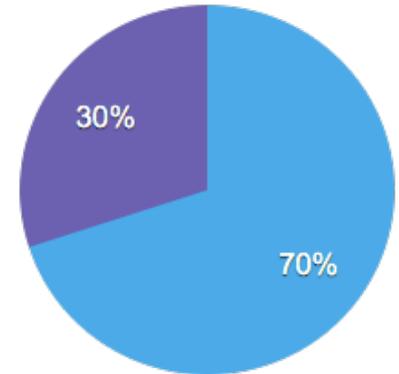
Year 2



Year 3



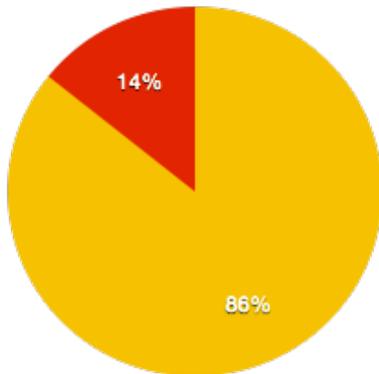
Year 4 + 6 months



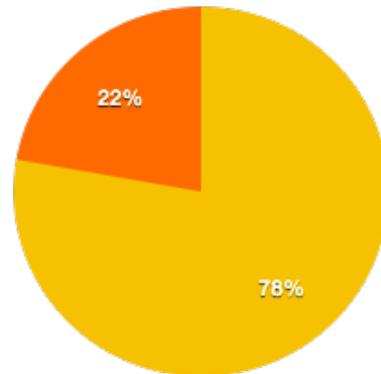
Reminder: 24% of our Members are from ITC

- Authors from 1 Country
- Authors from 2 Countries
- Authors from 3 or more Countries

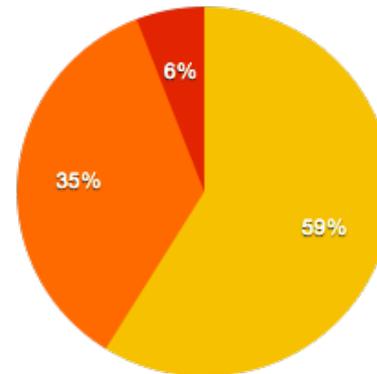
Year 1 (statistically non-significant)



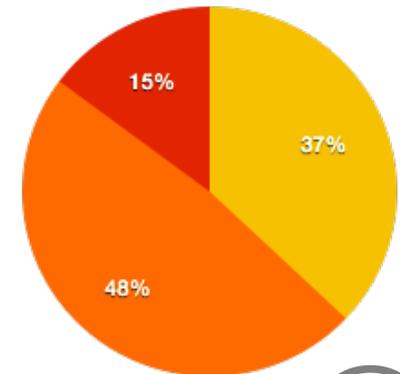
Year 2



Year 3



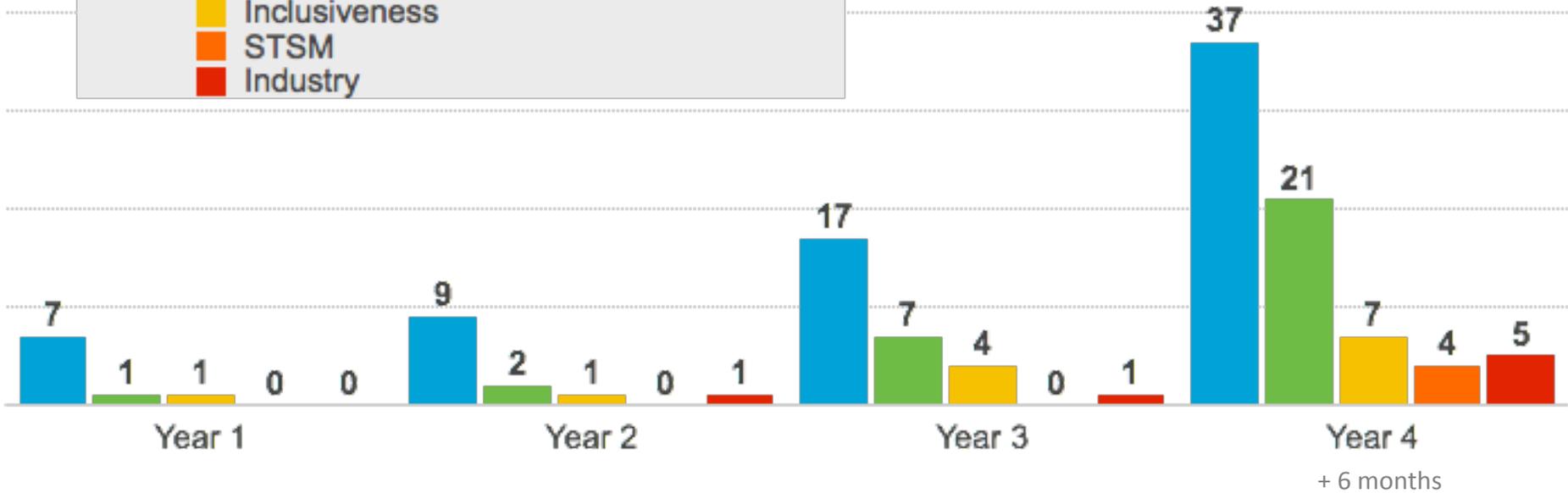
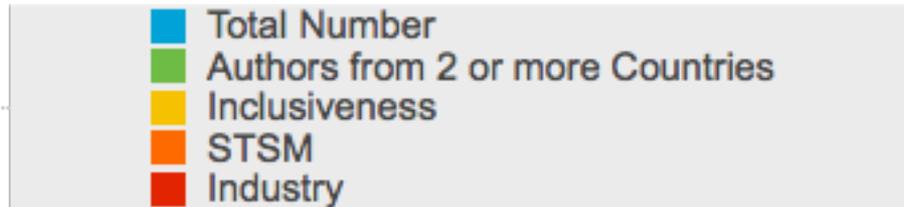
Year 4 + 6 months



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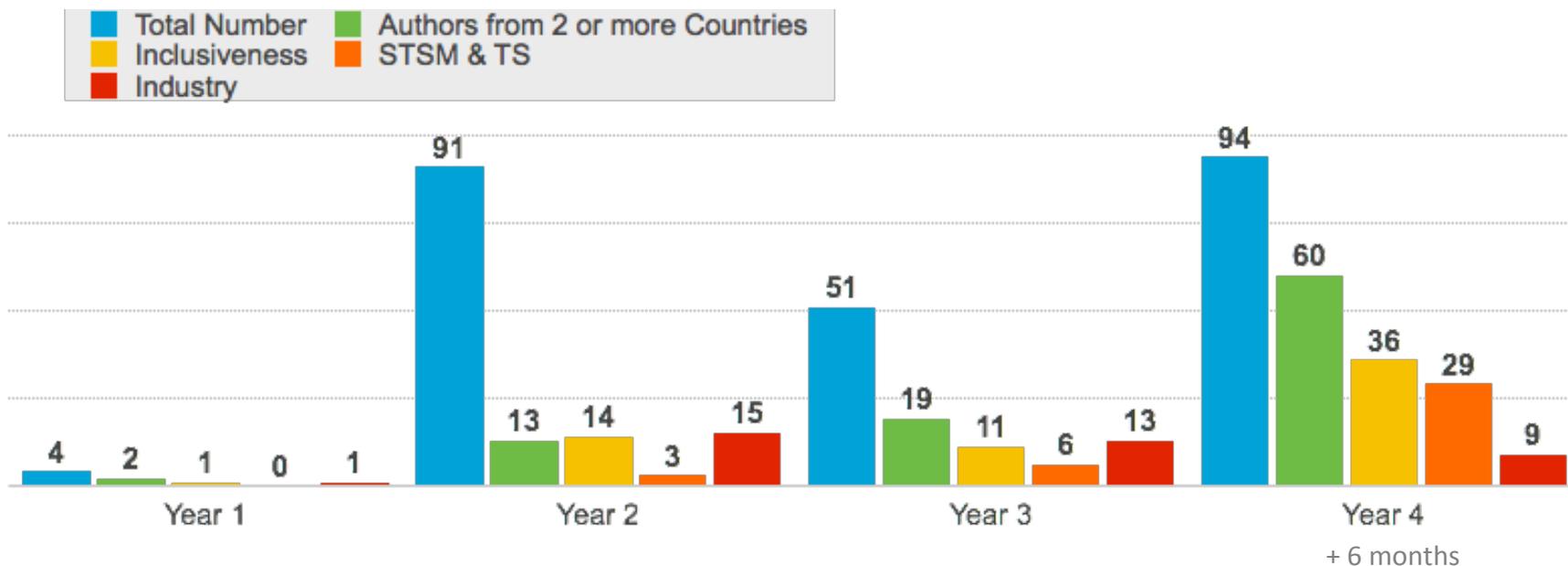


TU1208 Journal papers



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TU1208 Conference papers

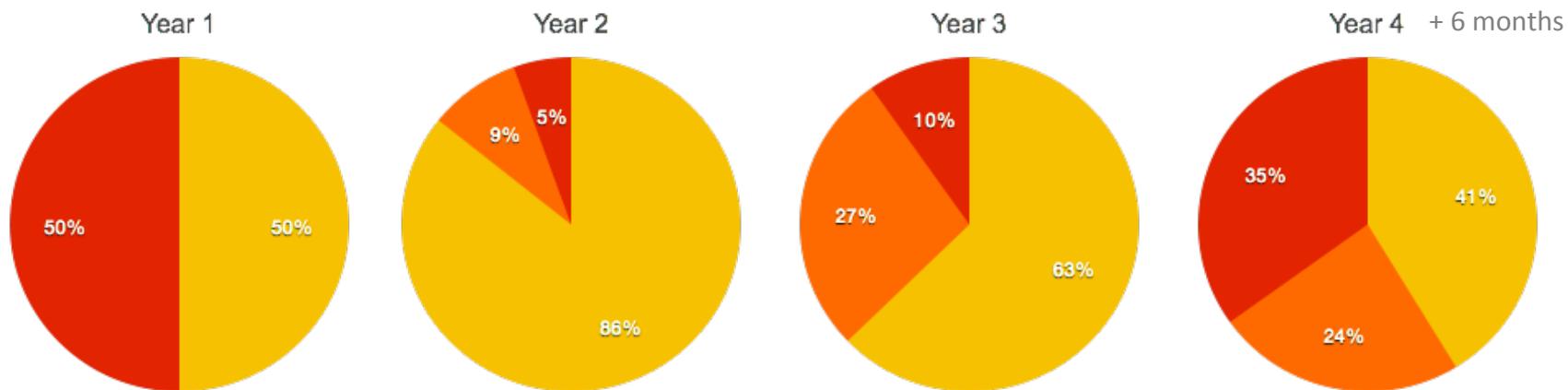
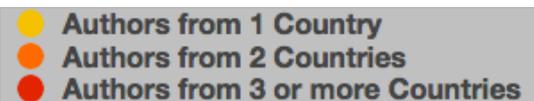
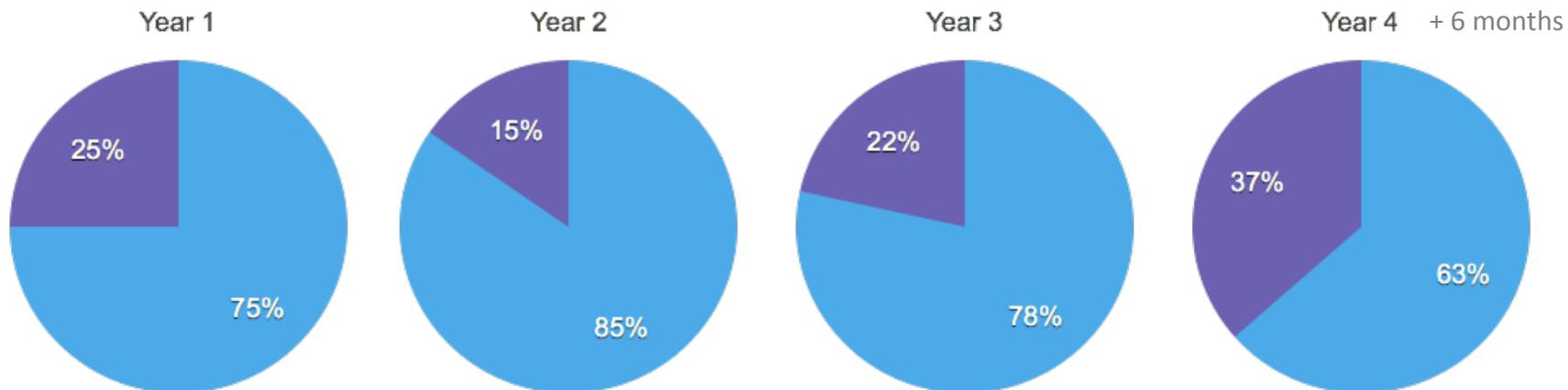


Total number in Year 4 similar to Year 2 (when we co-organized GPR 2014)... but the percentage of papers co-authored by Members from different Countries is completely different, as well as the number of papers from ICT.

Note also the high number of papers stemming out from STSMs and TSs, demonstrating the effectiveness of these COST networking tools.



TU1208 Conference papers



TU1208 Website

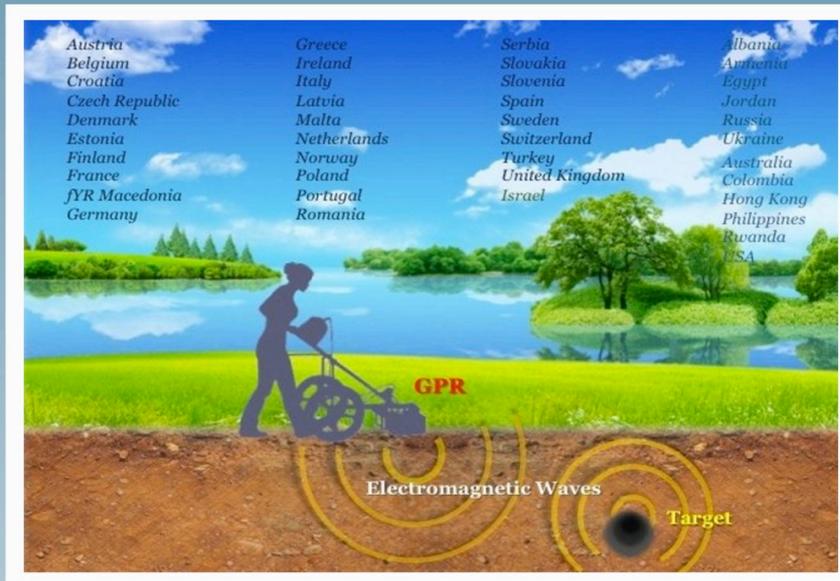
www.GPRadar.eu

- will remain active for an indefinite time and be enriched with new content, in order to disseminate and give maximum visibility to the outcomes of our research activities;
- will be the reference website for our future initiatives (association, journal, events) and turn into an interactive platform of exchange to sustain the dynamic of our network and to create new opportunities.



Action TU1208
Civil Engineering Applications of Ground Penetrating Radar
COST Success Story

HOME ABOUT ACTIVITIES EVENTS & DISSEMINATION RESOURCES GPR JOURNAL LINKS LATEST NEWS



Welcome on our website!

The COST Action TU1208 started on 4 April 2013 and is ending on 3 October 2017. The website will continue being updated and enriched after the end of the Action. If you wish to receive our updates via email, please fill in the [contact form](#).

The **main objective** of TU1208 is to exchange and increase scientific-technical knowledge and experience of Ground Penetrating Radar (GPR) techniques in civil engineering, whilst promoting a wider and more effective use of this safe and non-destructive method in the monitoring of structures.

Our research activities include all aspects of the GPR technology and methodology: **development and testing of radar systems and antennas**; design and application of surveying **procedures for the inspection of natural and manmade structures**, in civil and environmental engineering, cultural heritage and beyond; integration of GPR with complementary **non-destructive testing** methods; development of advanced electromagnetic modelling, inversion and data-processing techniques for **radargram analysis and interpretation**.



**TU1208 Members are immensely grateful to
COST – European Cooperation in Science and Technology
for funding the COST Action TU1208 and making this possible.**

**Heartfelt and infinite thanks to:
Mickael Pero and Carmencita Malimban,
Cristina Pronello and Thierry Goger,
for their outstanding support to the Action and to me
and for everything they taught me.**



COST is supported by the
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Endless thanks to all TU1208 Members who contributed to the extraordinary success of the COST Action TU1208.

**Thank you for your participation and priceless work.
Thank you for your enthusiasm, trust and friendship.
Thank you for sharing with me this wonderful experience.**

**Thank you for making the COST Action TU1208
a Success Story!!**



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COST

cooperation

sharing

open science

embracing diversity



humbleness

bottom-up

inclusiveness



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